Tevatron Accelerator Physics

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DOE/Lehman Review

February 24-26, 2004

Issues to be discussed:

- **Strong Coupling in Tevatron**
- **Orbit move at B0 (CDF)**
- **Recent Tevatron magnet multipole measurements**

General Motivations

- **Lifetime at injection**
  – Indicative of small ratio of aperture to beam size
- **Coupling correctors running strong**
  - Indicative of optics problem; ~10x stronger than 1984
- **Emittance growth at injection**
  –Larger for larger momentum spread (coalesced bunches)
  –Note: beam size dominated by momentum spread:

σ_β = sqrt($\varepsilon_N\beta/6\pi\gamma$) = sqrt(24/6/1.6) = 1.6 mm;

σ_δ = D (σ_p/p) = 4 m (0.7e-3) = 3 mm

Evidence for strong coupling

- **As discussed last review, …**
  - **Strong transverse coupling corrector settings in Tevatron:**
    - **Skew quadrupole (0th harmonic) circuit running strong to minimize tune split; $\Delta\nu_{min}$ ~ 0.3 if left uncorrected; around long time**
    - **Separate skew quadrupoles in long straight sections (esp. A0) required for effective global decoupling --> $\Delta\nu_{min} \sim 0.005$; strong correction**

Coupling (cont'd)

- Was thought perhaps IR quads were an issue (as in Run I), or perhaps that regions of systematically rolled dipole magnets (where large vertical orbit excursions were induced) were generating coupling; these effects could maybe account for 10% of the effect, at best
- One year ago (Feb 03), measurements performed which showed conclusively that source of coupling was distributed uniformly around the circumference…

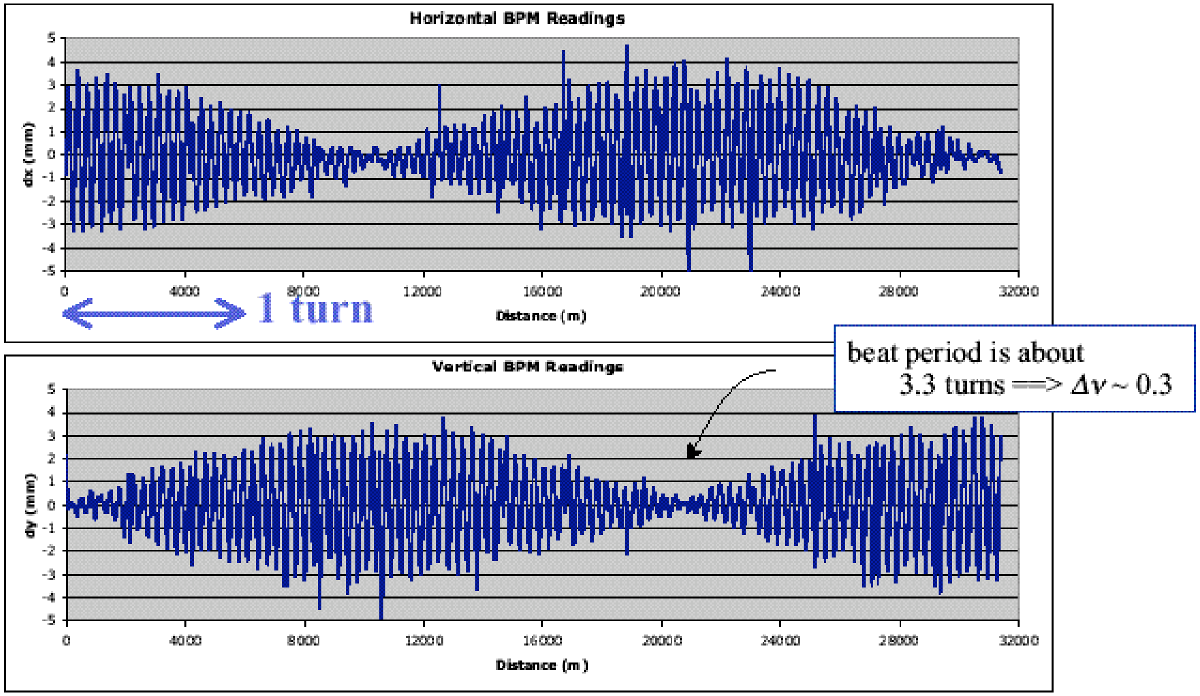
Coupling (cont'd)

- **Suggested that skew quad term, a_1, in main dipoles had large systematic value (1.5×10^{-4}/in.)**
- **Similar value agreed with the observed corrector settings…**
  - $\Delta\nu_{min} = 2Fa_1$

    $= 2\,(25\text{ m})(1.5\times10^{-4}/\text{in.})(\text{in.}/0.0254\text{ m}) = 0.3$
  - **and hence motion would couple to the other plane and back in ~3 turns**

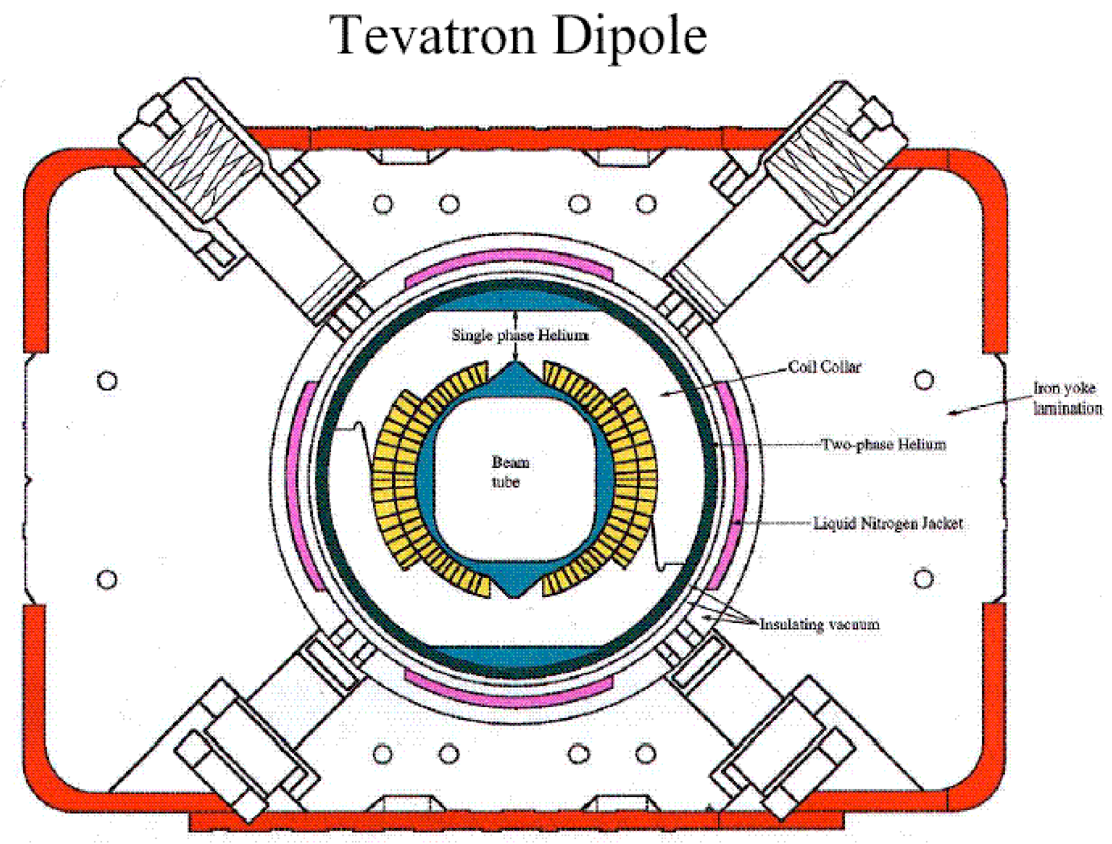
Coupling (cont'd)

Coupling Data, Feburary 27, 2003



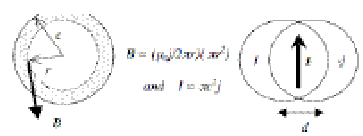
Data are consistent with systematic $a_1 \sim 1.4 \times 10^{-4}$/in   *G. Annala*

Tevatron Dipoles

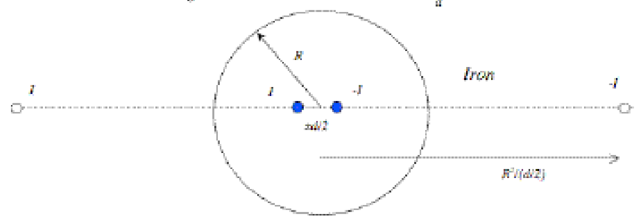


Coupling (cont'd)

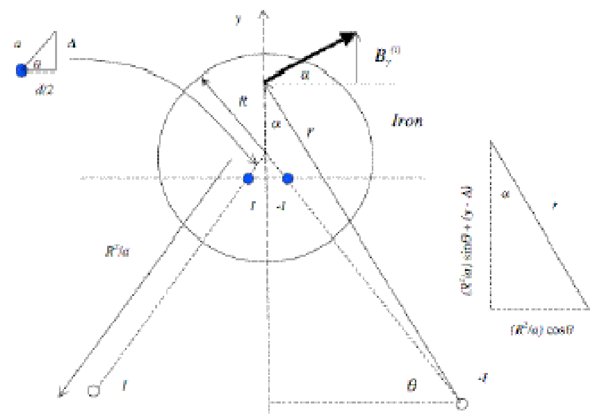
Start with uniform current density within a cylindrical cross section; look at field from 2 such cross sections, separated by distance *d*, and with opposite currents --> pure dipole field, B_c



Next, add an iron yoke of radius *R* and compute magnetic images, which will be located left and right, and which enhance the field in the center:
$B_0 \sim B_c[\ 1+(c/R)2\ ]$



Finally, displace the center of the yoke with respect to the center of the coil by a distance Δ, and compute the resulting skew quadrupole component
$a_1 = (dB_x/dx)\ /\ B_0$

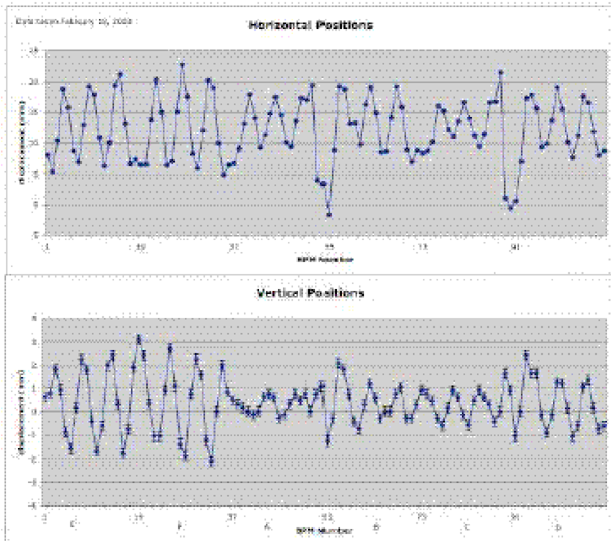


$$a_1 = 2\frac{(c/R)^2}{1+(c/R)^2}\frac{\Delta}{R^2} = 2\frac{0.25}{1.25}\frac{0.004}{(3.8)^2\text{in}} = 1.1\times10^{-4}\ /\text{in}$$

Coupling (cont'd)

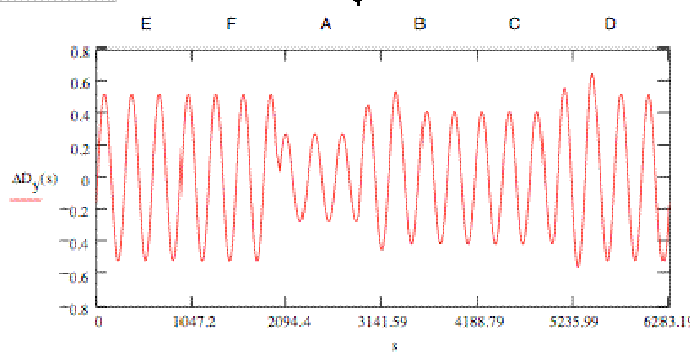
- During low-beta optics upgrade in Run Ib, several (6) skew quadrupole correctors were removed to make room for IR tuning quads; thus, there are "holes" of missing correctors on each side of each IR -- nominally would correct for ~53 dipoles at each IR (asymmetric w.r.t. center of straight section).
- The centers of these regions are not in phase with the main SQ circuit; thus an additional skew quad circuit -- 2 SQ's in the A0 straight -- is used which is more effective at further reducing $\Delta\nu_{min}$.
- A0 has horizontal dispersion, and thus represents a new source of vertical dispersion, accounting for the observed vertical dispersion pattern

Coupling (cont'd)



Closed Orbit data;
difference of two orbits with different momentum;
Note:
vertical dispersion --> ~60 cm

Simple calculation of dispersion wave generated by Tevatron skew quad circuits + large a_1 in main dipole magnets



Coupling (cont'd)

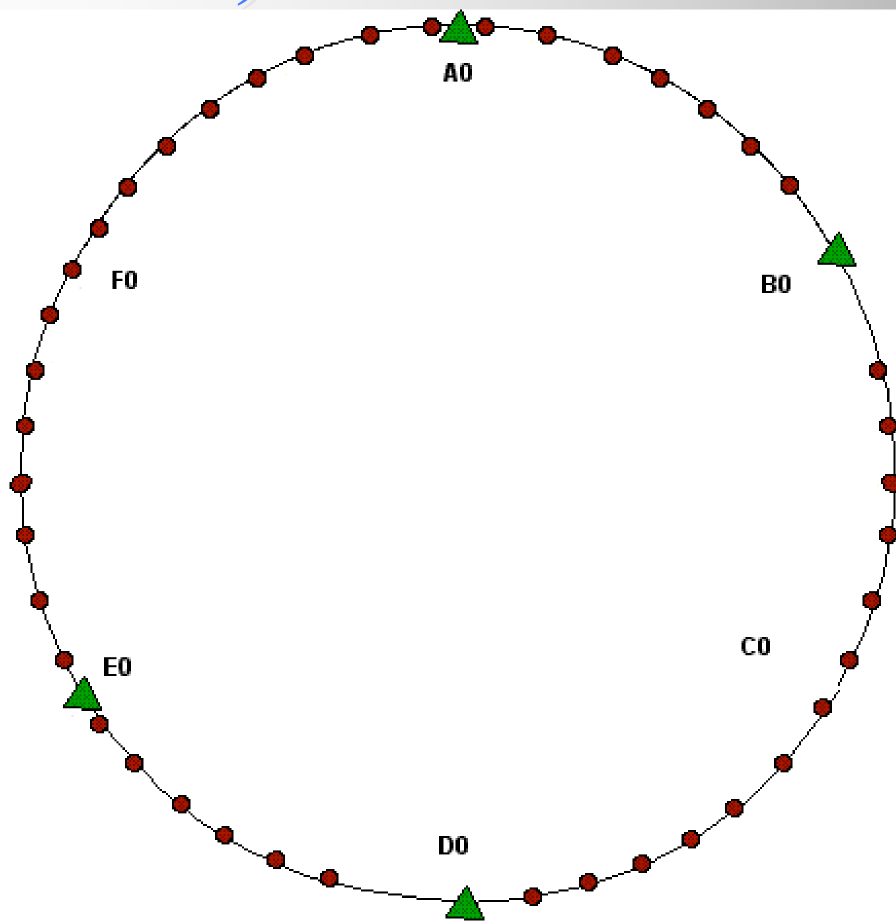
Skew Quad circuits:

circles:

main circuit

triangles:

independent circuits; A0 and E0 out of phase (by ~20-30^{o}) with main circuit



Shutdown Work

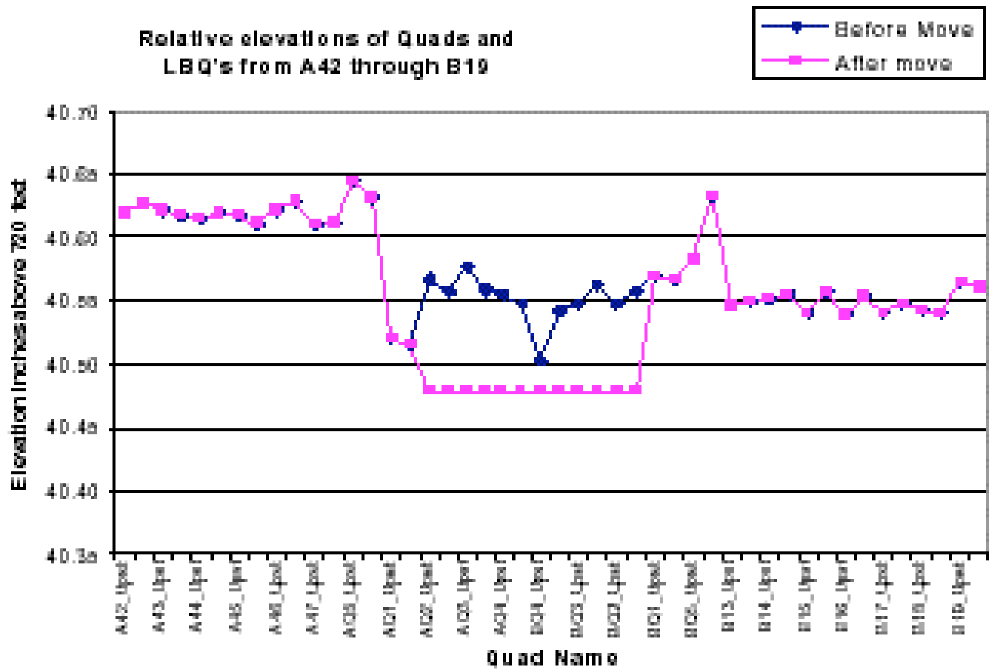
- **The 106 dipole magnets in IR regions where no skew quad correctors exist had their cold masses shimmed to remove their average a_1**
- **The skew quad circuits are now running at correspondingly lower currents:**
  - **SQ: 3A --> 2.7A ~ (3A)(1-106/774)**
  - **SQA0: 6.3A --> 4.9A (22% reduction)**
  - **Vertical dispersion improved as expected**
  - **Further improvement in SQA0 may be possible; have not had appropriate Tevatron study time to pursue**

Beam Trajectory at CDF

- **The Issue --**
  - **CDF detector has been moving vertically relative to the Tevatron orbit; was sitting about 4 mm below its desired level, and a 200 μrad angle across the detector had developed.**
  - **Due to this, the CDF detector was experiencing about 25% inefficiency in tagging B-mesons with the Silicon Vertex Detector.**
  - **Meanwhile, magnet surveys showed that the IR triplet magnets were out of alignment, plus several Tevatron vertical steering magnets were running near their operational limits.**
  - **Decision was made to attempt to straighten out triplet magnets and to steer the Tevatron beam down and through the center of the quads, reducing corrector strengths where possible.**

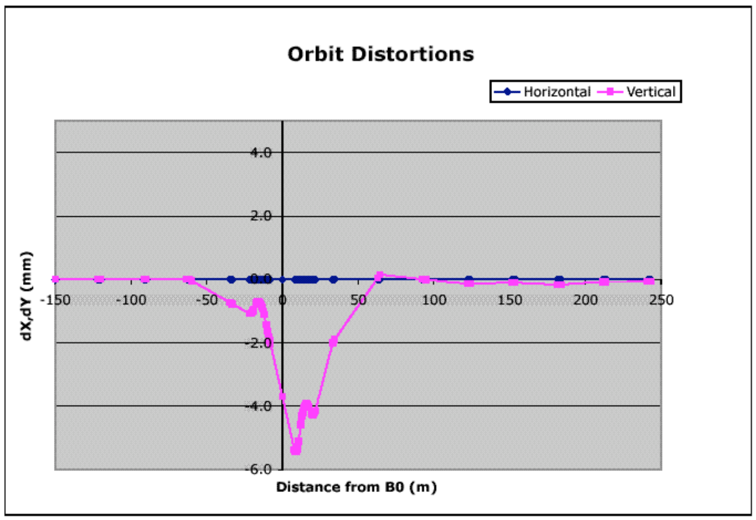
CDF / B0 Alignment Effort

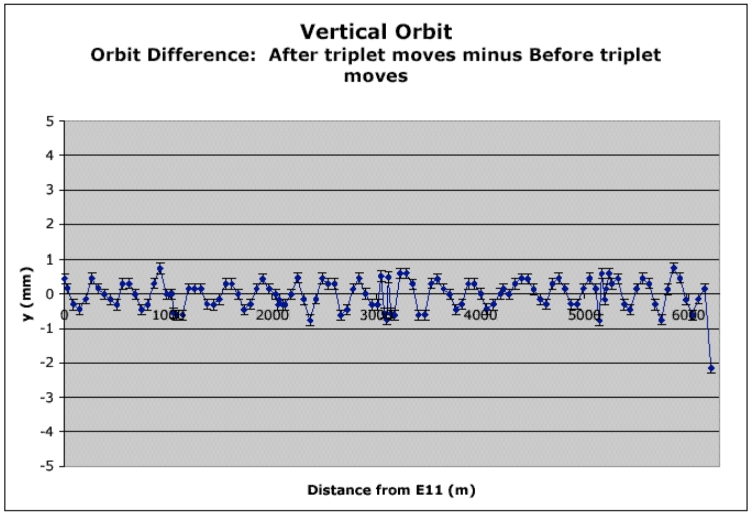
- **People involved:**
  - **M. Syphers, J. Annala, N. Gelfand, V. Lebedev, plus J. Volk, V. Shiltsev, others, plus CDF**



CDF / B0 Alignment Effort

Expected closed orbit change:





Dead-reckoned correctors after magnet moves; resulting residual orbit outside of Interaction Region ~0.5 mm amplitude (easily corrected)

Multipole Measurements in Tevatron Dipoles

- Input slides from Pierre here…

SUMMARY OF PRESENT KNOWLEDGE ON b2 DRIFT AND SNAPBACK IN TEVATRON DIPOLES

Pierre Bauer for the
TD/D&T department

- b2 Drift and Snapback in Tevatron Dipoles

- Results of Recent Measurements

- Proposal for Improvements of the b2 drift/SB Compensation

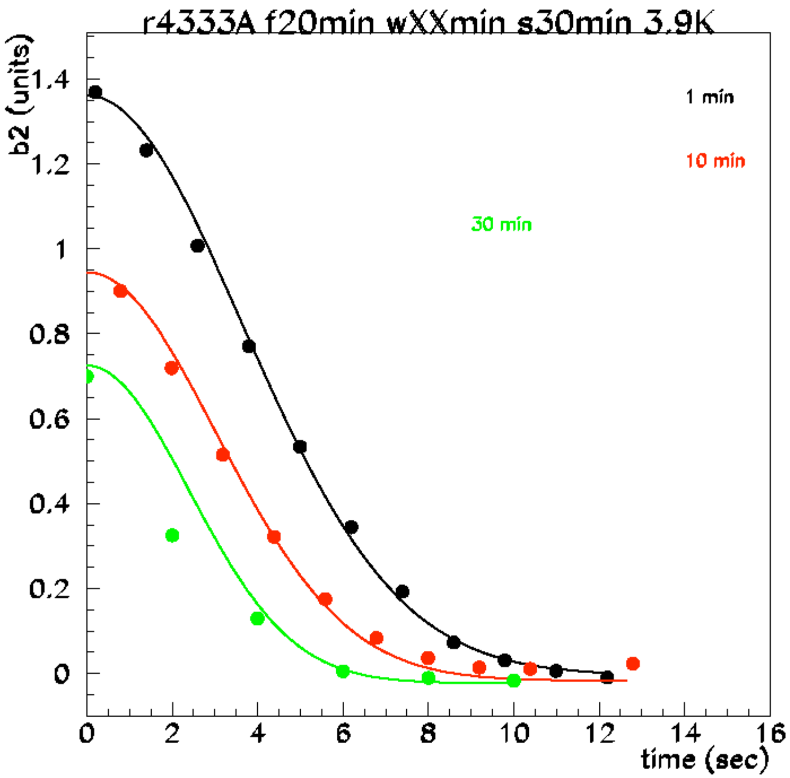
- Summary

What do we know about b2 in Tevatron Dipoles

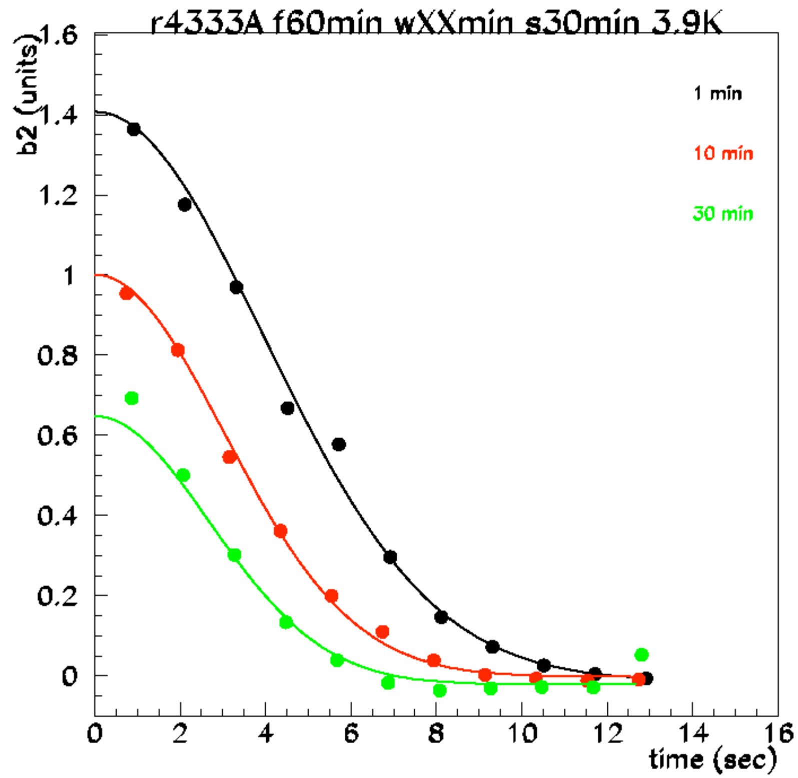
- ~ 14 units of geometric b2 in body, strong negative geometric b2 spike (~-600 units over 10 cm) in ends; body end average b2 of all installed dipoles is ~1.45 units.
- geometric b2 varies by 1-2 units along the magnet ("sausaging"). This effect contained in the above numbers.
- b2 variation along the magnet in periodic pattern of ~10 units (or more) amplitude (not yet measured, but existence proven); Beam and magnetic measurements see no pattern (average to zero, pattern period ~ 2.5").
- average b2 hysteretic loop width at injection of all dipoles installed in the Tev:~10 units; (This width underestimates the real width because it contains an unspecified amount of drift which was not recognized during production measurements.) hysteretic width increases by ~15% for 1 K temp change, but is otherwise invariant (on ramp rate, powering history,..etc)!
- b2 at injection drifts by 1-2 units after 30 mins with a logarithmic dependence; large magnet-to-magnet spread in the dynamic properties; dependence on powering "history" will be discussed next;
- b2 drift and snapback characteristic in the ends does not appear to be different from that in the body.
- Temperature, apparently, does not affect drift and snapback.

b2 Measurement Example: Snapback vs. Back Porch (BP): TC1052

20 min FT



60 min FT



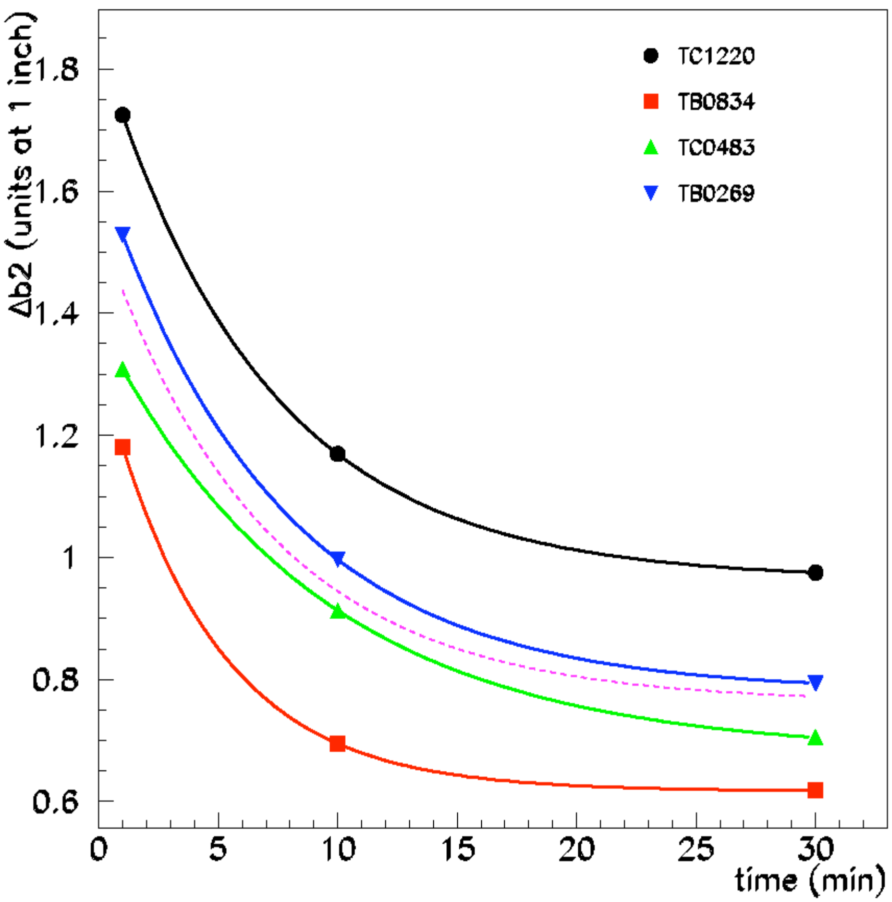
Example of SBs after 30 min at IP in magnet TC1052 for different pre-cycle BP and FT times. Data clearly show that the back-porch affects the drift amplitude more than the pre-cycle flat-top!

Proposal 1: Fixing (& Extending) the Time on the Back-porch

The back-porch is clearly the pre-cycle parameter with the strongest impact on the drift amplitude. The longer the back-porch, the less drift.

The back-porch time needs to be fixed (preferably at t>10 mins), thus requiring an automation of the Tev sequencer.

The "20 sec-issue", (TCHROM takes time 20 secs before actual end of BP as input for the calculation of the drift and SB feed-forward compensation) needs to be resolved.



Proposal 3: Improve Algorithm for Snapback Feed-Forward Correction

- **Polynomial snapback (currently used in Tevatron):**

  $b_2(t) = \Delta b_{2,0}\,(1 - t^2/t_0^2)^2$

- **Exponential form:**

  $b_2(t) = \Delta b_{2,0}\,\exp(-t/t_0)$

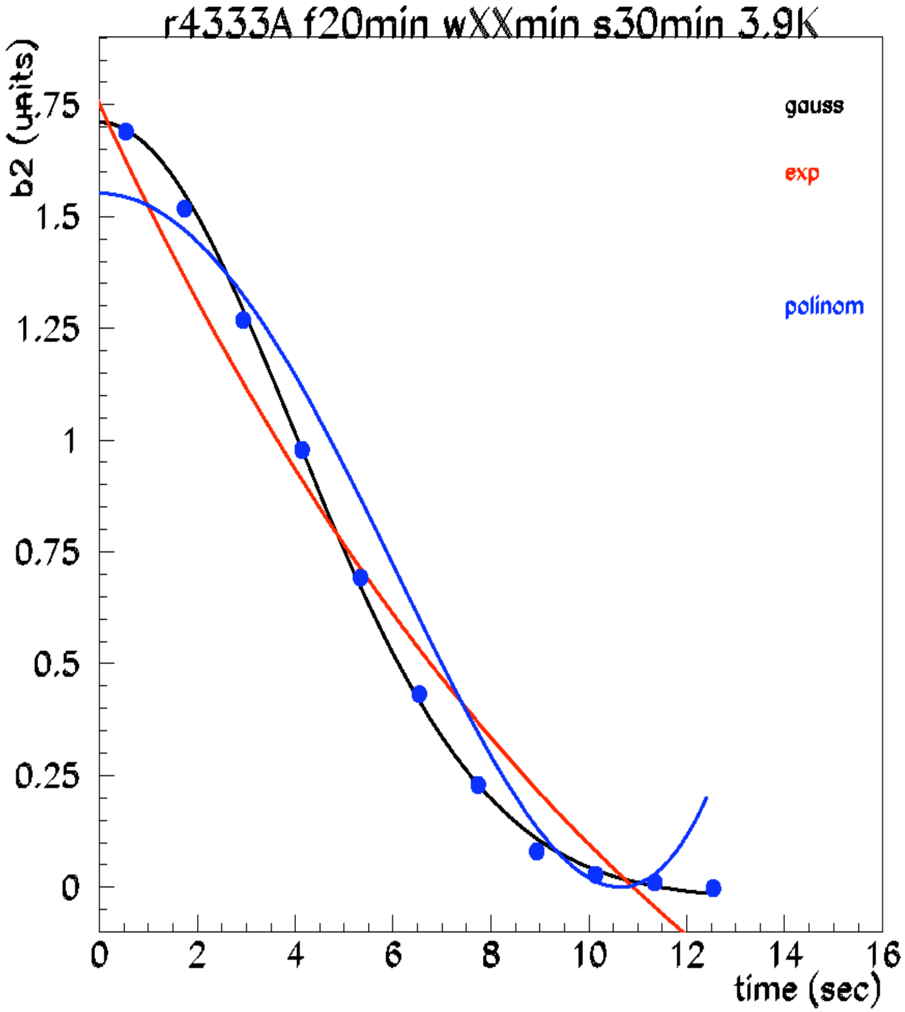
- **Proposed parameterization:**

  $b_2(t) = \Delta b_{2,0}\,\exp(-(t/t_0)^2)$

- **In addition we parameterize the drift amplitude Δb_{20} and the SB time t_0 as a function of the durations of the pre-cycle parameters (IP,BP,FT)**

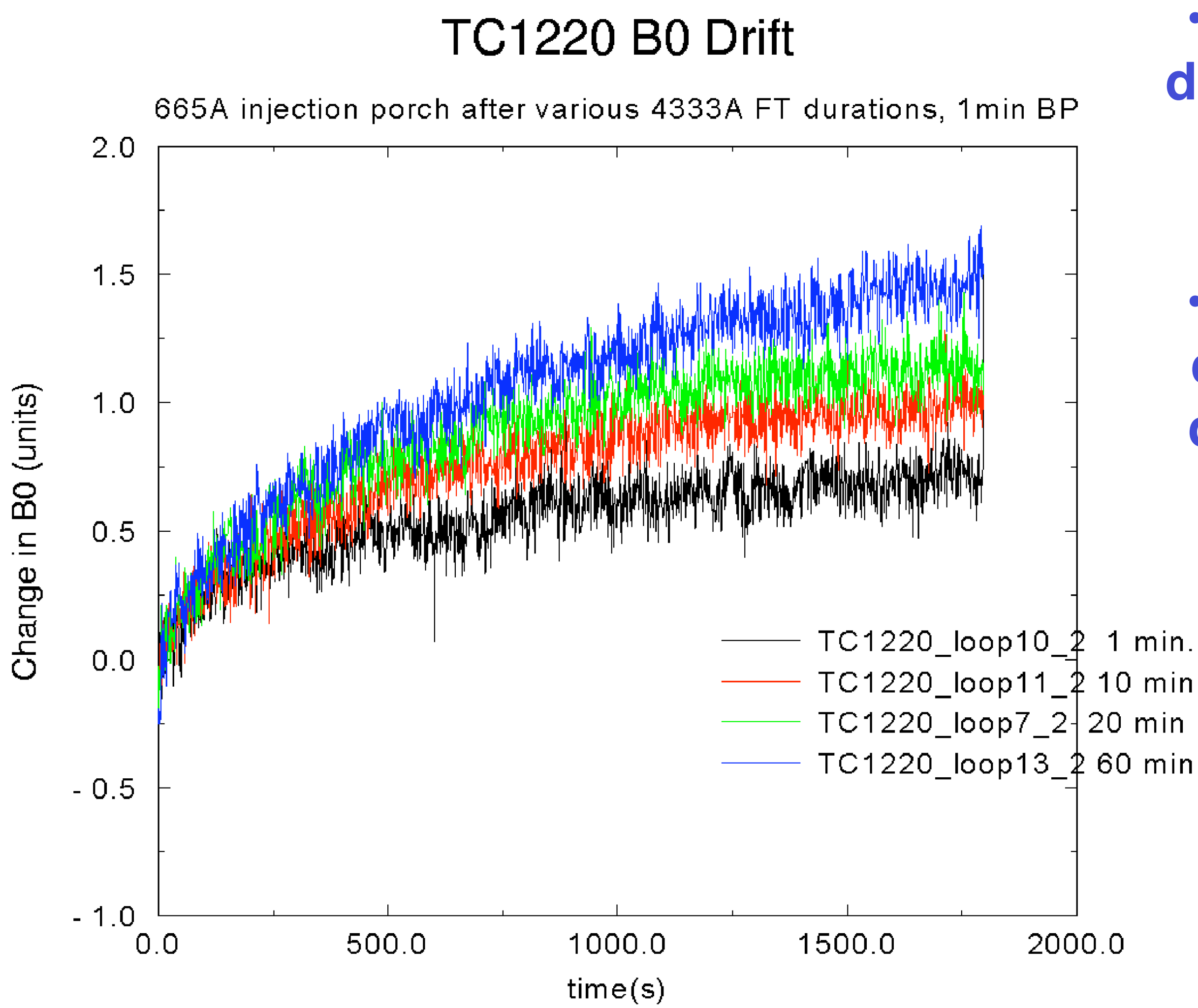
  $\Delta b_{2,0}{}^*, t_0{}^* = p_1\,\exp(-t/p_2) + p_3$

* These parameters are in fact correlated $t_0 = t_0(\Delta b_{20})$!



Magnetic Measurements: Main Field Drift

First evidence of main field drift in Tevatron dipoles:



- **b0 drift amplitude dependence on pre-cycle parameters similar to b2 drift**
- **b0 drift amplitude correlated with b2 drift amplitude (as expected)**

B0 drift at injection in TC 1220 after pre-cycle with 4 different FT durations.

Summary – Proposals for improved b2 fit

•Fix (and extend) back-porch time

•Reduce # of beam-less pre-cycles following a Tevatron quench from 6 to 1;

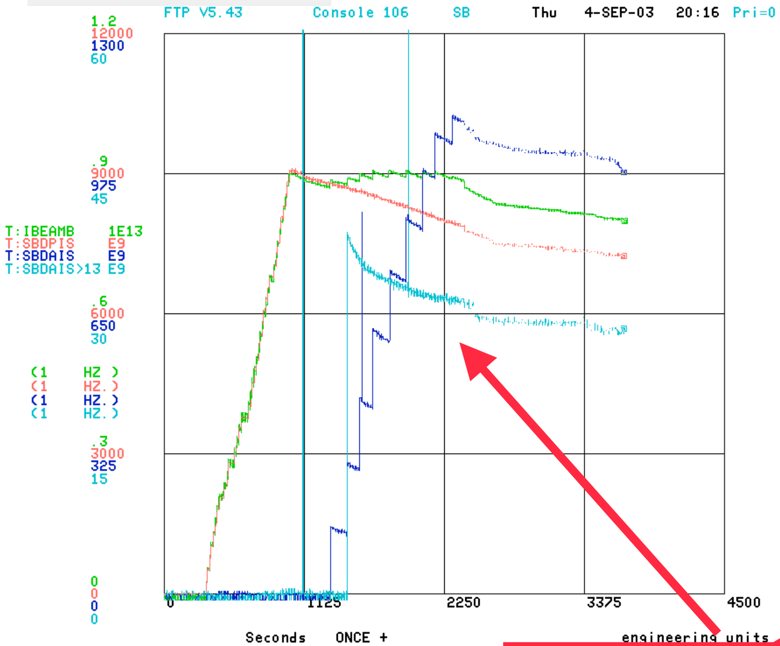
•Improve b2 SB fit→ Gaussian?

•saturation of flat-top duration effect on drift amplitude and absence of effect of front-porch duration → foundation for elimination of pre-cycle

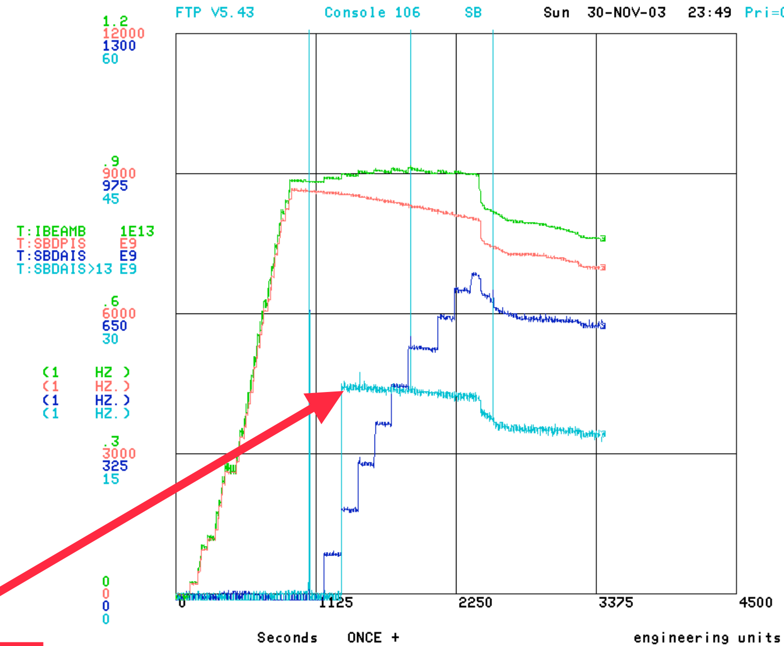
•Improve drift fit – a parameter in the old fit is history dependent although it shouldn't be, a double exponential appears to be slightly better than the log fit.

Bottom Line

Sep 03 store



Nov 03 store



Pbar intensity

Now, even better!

Conclusions

- Realignment of Tevatron increased beam aperture
- Realignment of CDF low-beta quads better centered beam trajectory through this sensitive region of strong focusing elements
- Smart Bolt corrections improved global and local coupling, improved control of vertical dispersion
- Better control of longitudinal emittance from Main Injector improved momentum spread at injection, better coalescing efficiency
  - Reduced beam size (horizontal, mostly)
  - Made any remaining dispersion mismatches less prone to emittance growth
- As result, 150 GeV lifetime greatly improved, leading to larger efficiency of particles to low-beta, higher luminosities
- Working to improve efficiencies during acceleration snap-back time